DOCUMENT RESUME

ED 452 027 SE 064 380

AUTHOR	Pujol, Alfonso
TITLE	Educating for Creative Thinking in Engineering.
PUB DATE	1998-08-00
NOTE	5p.; Paper presented at the International Conference on Engineering Education (18th, Rio de Janeiro, Brazil, August 17-20, 1998).
PUB TYPE	Opinion Papers (120) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Creative Thinking; Creativity; Educational Environment; *Engineering Education; Foreign Countries; Higher Education; Teaching Methods; *Technology Education
IDENTIFIERS	Argentina

ABSTRACT

The present rush to liberalize the economy in most countries, is for some people a matter of principles and, for others, the hard cost of getting rid by "elimination" of the vices derived from statism and protectionism. In many countries, that kind of economic structure had crystallized their productive systems as a consequence of restrictions imposed on individual and group initiative, and made it difficult to keep pace with the rest of the world. Particularly in societies on their way to development, an always increasing number of individuals had found it easier to fulfill their ambitions by viciously taking advantage of the condescend complicity of their fellow citizens. The problem is that it is easier to get rid of economical systems than to change behavioral patterns. In the field of technical education, that slackened behavior makes goals almost unattainable. Creative thinking, prime mover of technical innovation and scientific and technological research, has been one of the principal casualties of that behavior. The article recalls some well-known educational principles and teaching practices, in order to help delineate policies and the strategic management of technical education. Even if they may seem obvious by themselves for an observer of an already well organized society it is not such a simple matter for somebody from an "emerging" nation. It will be a good contribution if the article is of some help to the work of deciding which principles and practices should be sustained without concessions and which others may be relaxed in favor of other needs. (Author)

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ED 452 027

Educating For Creative Thinking In Engineering

Alfonso PUJOL
Universidad de Buenos Aires
Facultad de Ingeniería - Departamento de Hidráulica
Av. Las Heras 2214
(1127) Buenos Aires, Argentina

Abstract *– The present rush to liberalize the economy in most countries, is for some people a matter of principles and, for others, the hard cost of getting rid by "elimination" of the vices derived from statism and protectionism. In many countries, that kind of economic structure had crystallized their productive systems as a consequence of restrictions imposed on individual and group initiative, and made it difficult to keep pace with the rest of the world. Particularly in societies on their way to development, an always increasing number of individuals had found it easier to fulfill their ambitions by viciously taking advantage of the condescend complicity of their fellow citizens. The problem is that it is easier to get rid of economical systems than to change behavioral patters.*

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Helping Think Creatively

Creativity is defined as *"a quality of intellectual activity"* that in varying degrees is always present in human words and deeds. The act of human creation is based on reasoning, the availability of previous concepts and a favorable emotional disposition.

In technical activity, the word "innovativeness" is frequently used and refers to effecting changes or doing something in a new way. It relates to creativity in a restricted manner and is a primary thrust for development and a producer of wealth in modem societies.

The relative depth of basic courses in mathematics, physics and chemistry, the orientation, both theoretical and practical, and the type of information given to instrumental and professional courses, put practical limits to the expectations of creative thrust for the different levels of technical education. However, it should be clear that learning of those subjects, basic, instrumental or professional, provides the tools and the material to nourish creative thinking but do not train it nor make a habit of doing it.

The way an educator teaches may get creative thinking to spring up. It is an atmosphere that triggers it in a technical high school, in an engineering school or elsewhere. That way which may be called "implicit" consists of an empathic relationship between the teacher and his students. It is an environment that may spring easier from a teacher who has already experienced the feelings of creative thinking. He describes usual or recently found solutions to technical problems, asks students to solve problems different from those explained in class, poses questions whose answers may be found in the library, leaflets from manufactures, interviews with experts, etc.

Due to the success of academic research in leading countries, some of their universities already are teaching the techniques for that kind of research [1]. Those techniques are first applied to look for alternatives of problems already solved and later to problems still unsolved. This is an explicit way of helping think creatively but it is implicit on that it depends anyway in that special atmosphere that has already been mentioned.

Finally, a completely explicit way consists on asking for new knowledge, scientific or technological, as the result of academic research. In theory, that is the main requirement for conferring the doctoral degree.

The comparison of that conceptual frame with technical education practice in many "emerging" countries shows that a combination of severity and flexibility is needed when applying it to actual cases. The question is that a behavioral struggle is the crossroad from wishes to deeds.

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Creative Thinking According To Different Levels Of Technical Education

From the point of view of thinking creatively or being innovative, different things may be expected from graduates of technical high schools (called secondary schools in some countries), engineering schools and university graduate programs leading to master and doctoral degrees. Of course, those differences are a matter of opinion.

One would expect a *technical high school* (secondary school) *graduate* to apply his craft with sound judgment, to put into play his technical abilities within given limits. The education imparted upon him is mostly instrumental, strictly circumscribed by the requirements of his craft. He has not been prepared to change his technological basis but may possibly enlarge its applications or improve its tools. In the latter case a high school technician may be said to be innovative and levels up to a college graduate in that restricted manner.

The engineering college graduate should be able to deal with intricate technical problems, depending on his experience. His basic education in mathematics, physics, and/or chemistry, is at its best just enough to allow him to improve or change his technological basis and at its minimum "instrumental" in a sense similar to that afforded to a high school technician. In the former case, an engineer may feel at ease working with the "engineering science" corresponding to his specialty and become a Research and Development (R&D) researcher, once again in a restricted manner as he will not be prepared to contribute to the improvement of that engineering science. The term "engineering science" has been used here as a reference to that part of a scientific field which directly "informs" a technical one.

Finally, the *engineering doctoral graduate* should be able to contribute to the enrichment of the "engineering science" corresponding to his own field or to related fields. The mastering of advanced mathematics, physics, and/or chemistry is an unavoidable requirement as it is the training on the techniques of academic research. A restriction is still present: the contributions of an engineering doctor are usually limited to his "engineering science".

In conclusion, creative thinking is a valuable aptitude at every level of technical activity but one should keep in mind the diverse extent imposed by formal education on the average performance that can reasonably be expected from graduates of different levels.

Environmental Conditioning For Creative Thinking

Formal education gives the tools that technicians need to think and work creatively. However, unwanted constraints may be embedded in the academic system itself originating from the shortcomings of social and economic environment at large.

As in every social body, where groups of diverse cultural and economic power interact but do not coalesce in one common character and destiny, the society of nations interacts increasingly but its individual members will not reach an equal level of culture and affluence. In a society, the upper echelons find it natural to work out every conceivable opportunity (be it a banker or a novelist, a businessman or a priest, a politician or a saint... and the like) but in the lower ones expectations are much more limited (be it a white collar clerk or an industrial worker, a basketball player or a nightclub dancer...). Expectations are a state of mind, rational and emotional.

An expectation is what is actually felt to be as an opportunity or as a goal to fight for. In most countries to becoming an astronaut is just an unattainable dream and different people are prone to feel in diverse ways about it. Confronted with what only few people can do, most of the peoples in the rest of the world feel that that or other similar opportunities are not for them. They inhibit themselves not only of trying to reach those goals but more often than one would like to think of accomplishing other goals actually to their reach. Few others will try to be a part of it but are confronted with the difficult task of deciding what is good for them. The academic circles of some "emerging" countries are quite dubious on deciding what to do: as elsewhere, marginal groups will feel part of the first world if the "Journal of Astronautical Research" (not to be confused with the real one, if it exists) accepts their papers for publication. Reasonably enough, significant contributions will come from scientific or technological centers in countries with the potential to do it and, consequently, our outsiders will possibly make mostly marginal contributions. Even if they read all related papers and try to find not well known points to clarify, the other people will not wait for their contributions to send astronauts out there.

Not that particular delusion but many others of a more subtle nature are more common in some countries than one might imagine at first thought. The conscious or unconscious outcome is that some people restrain their imagination afraid to mimic delusive behaviors. In a similar manner, constraints are unwillingly imposed in many activities, including educational, that hamper creative thinking.

Technicians with secondary (high school) education are almost free from those constraints. Their technological basis is imposed on them by formal education and/or in job training. There exists a close relationship between needs and results that shapes a positive atmosphere on the

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improvement of their abilities. Anyway, a quick reaction to rapidly changing needs is a challenging task at this level of the educational business. The challenge is not for the technician to be creative while working within the limits of his technological basis, but it is for the educational institution to quickly adapt or change that basis in accordance with new needs and techniques.

College engineers of "emerging" countries are in the battlefront, on the water divide. Their profession compels them to go ahead, innovatively or not, at least in their daily work. However, when it comes to change or enrich their technological basis many drawbacks make their appearance. The most evident one is that college professors are poorly paid, partially because universities are sometimes overcrowded with their alumni, now turned into professors for lack of opportunities elsewhere. That situation is not the best one to retain well-qualified educators and, consequently, students may not be educated in an environment propitious to creative thinking. To change that situation the society at large should become conscious of its importance and allocate enough and well distributed means. In addition, actions addressed to correct those faulty situations should be programmed in such a way so as to avoid or override the resistance of the very same faculty members, afraid of the outcome.

Most of the contradictions between ideals and reality are found in graduate education and research. In "emerging" countries, industry does not demand much from their incipient engineering research systems, more so because most of the industry is subsidiary of foreign companies and brings needed know-how from abroad. Therefore, almost all of the master and doctoral research topics are chosen without the guidance of industrial requisitions. The usual way of selecting research topics consists of conducting a literature search in well-known publications. However, only publications originated in advanced countries are taken seriously even if they have the disadvantage of being addressed to other needs and requisitions. It would be better if one would take the time to analyze which areas of knowledge may promote domestic development and only then search for related foreign literature. Besides, one should keep in mind that topics related to the "engineering sciences", as defined before, only contribute indirectly to the welfare of a society, which does not mean that they should be discouraged.

The point here is to decide which part of the research effort should be directed to the needs of a given society and which other part may be allocated to the progress of the engineering sciences. To do it domestic technical and scientific literature should become valuable enough so as to serve as a reference for domestic research needs. If a society cannot depend on its own judgment to decide about its own businesses will depend on others, it will be a dependent society.

The Long Way Toward Technical Creative Thinking

In previous sections, some criteria have been delineated for encouraging creative thinking in Engineering. Actually, most of the expressed ideas are known by almost everybody. The problem remains on how to put them at work.

It is assumed that a willing society is already on its way to development and is already convinced that technical innovation is the only real way to increase material wealth. In such a case the question remains on how to promote creative thinking as the necessary engredient for technical innovation.

On the way of doing that, some people are only thinking on it but doing nothing, others are trying and still others are already going in the right direction. Surely enough, there does not exist a single and simple recipe for cooking it. Even to copy what advanced countries are doing right now is not so simple, since they are in a different stage of development. Any case, one should dare to think creatively, right or wrong, in a trial and error procedure.

The posed dilemma about overcoming a stagnant condition consists on deciding if it should be done little by little or suddenly. Most probably it is not a dilemma, one starts suddenly and obtains results little by little. The decision by itself is as fast as a neuronal link allows but a critical mass should be attained to start with it. That critical mass refers to a sufficient number of influential people or leaders acting consciously on the same direction.

The preceding paragraph avoids the subtleties of the situation. Some degree of relaxation may be allowed when gauging results but that should be based on an exacting agreement of a timetable of increasing demand, applied and controlled from the very beginning.

For example, let us assume that an Evaluation and Accreditation Board has been established to gauge the performance of institutions of graduate education, taking into account means and results. Suppose that levels of positive accreditation are to be awarded from a minimum "C" to a highest "A", with the understanding that for an "A" the unavoidable condition is that an institution should exhibit the production of innovative, original contributions, technical or scientific, worthy to the society at large. If accreditation certificates are to be issued periodically, it may be accepted for the first time that prestige is good enough for an "A". However, prestige alone cannot be enough to get an "A" the second time certificates are issued. That second time, it may be agreed that for an "A" some few contributions should be considered original and innovative by an external reviewing committee. After several evaluation cycles, for an "A" it might be needed to prove that some of the contributions already published have

become part of technical texts and procedures used by others aside from the evaluated institution.

Otherwise, if the agreement is not honored it will be better but the most difficult to impose stringent demands from the very beginning.

Concluding Remarks

In this article, various factors affecting innovative ability or other degrees of technological or scientific creativity are considered with respect to the engineering profession in "emerging" countries. Summarizing it has been stated that:

1. Regarding different levels of technical activity, formal education imposes diverse extents of creative thinking on their graduates: technical secondary school (high school) graduates are expected to be creative under the constraints of their "technological basis"; college graduates may contribute to expand or change their "technological basis" but without contributing to corresponding "engineering sciences" ; finally, engineering doctoral graduates are expected to contribute to their "engineering sciences" but usually not to science at large.
2. With respect to secondary technical education, the demand for needed technician is so explicit and self evident that there is not much room for mistakes or slackness. The challenge here is to quickly understand and take due measures in reaction to rapidly changing needs. However, the challenge is not for technicians graduating from those schools but for educational institutions to quickly adapt or change their technological basis in accordance with new needs.
3. Engineering graduates are supposed to show their ingenuity while working in their profession. Engineering schools (in not enough developed countries) suffer from many shortcomings arising mainly from misconceived policies that results in insufficient or badly allocated funds. To change that situation the society at large should become conscious of its importance and allocate enough and well distributed means.
4. University institutions must not become overcrowded with students and badly paid professors. Actions addressed to correct that situation may need to be programmed in such a way so as to avoid or override the eventual resistance of faculty members and students alike, sometimes afraid of the outcome.
5. Contributions to science and technology are one of the two most important products of doctoral work, the other being the training for academic research. But both of them might be blurred when working on marginal topics. Dazzled by science and technology of advanced countries, research groups of some other countries sometimes forget to gauge their own possibilities and their chances to contribute to science and the society that supports them.
6. About research effort itself, the point is to decide which part of it should be directed to satisfy the needs of the society and which other to the progress of the engineering sciences. To this end, domestic technical and scientific literature must gain enough credit so as to serve as a reference to domestic research needs.
7. With respect to the evaluation and accreditation of institutions, some degree of relaxation may be allowed when gauging results. However, the parties involved must agree in advance on a program of diminishing relaxation with time, made known to everybody and controlled from the very beginning. Otherwise, if such an agreement does not work it would be better to impose stringent demands from the very beginning.

Those statements are not new and have been discussed elsewhere many times. However, one should become aware that the underlying problem is not one of means and know-how but one of finding effective remedial treatments to social disorders.

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